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A Triple Frequency Echo Sounder

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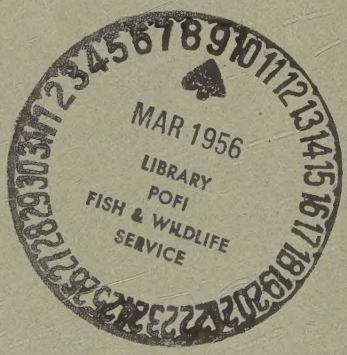

LONDON: HER MAJESTY'S STATIONERY OFFICE
1955

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A Triple Frequency Echo Sounder

Introduction

In experiments with dead fish hung from below an echo sounder (Cushing and Richardson, 1955) significant differences between signals returned from cod and herring were found, using any one frequency; it was further found that a lower frequency would be best for cod and a higher frequency best for herring. This required testing on fish shoals in the sea, partly because in the experimental work some part of the echo received might have been due to the frame and partly because the arrangement of the dead fish in a shoal was an artificial one.

Another subject for investigation was that of the variability in signal amplitude, which Mr. B. C. Browne had suggested to us might well be proportional to the number of fish per unit volume.

In order that we might investigate these two points, a triple frequency echo sounder was designed and made for us by Messrs. Kelvin and Hughes. This was used at sea on five cruises, on three of which the target fish were identified independently, the other two being of interest for comparison. It will be seen that this work confirmed the differences in returned signal from cod or herring at different frequencies and also showed differences in coefficient of variation that are statistically significant.

The machine may be briefly described. Three oscillators, of 10, 14 and 30 kc/s respectively, were used as transceivers and were mounted alongside each other in a wooden fairing; each oscillator was sealed in glycerine behind a thin metal plate ($\frac{1}{16}$ in.) within its reflector. The fairing is shown in Plate I (*a*) mounted at the end of a long tubular steel framework. The steel framework was secured by steel pins to brackets on the ship's rail; a wire guy was run from the fairing to the forward gallows and another was run aft to the ship's casing. When in use, the oscillators were securely held three or four feet beneath the sea surface; when finished with, the framework was hauled in, pivoting on the ship's rail and was lashed firmly, either against the ship's casing (as on the Ernest Holt) or on the foredeck (as on the Sir Lancelot). Plate I (*b*) shows the framework lashed on the Ernest Holt.

Three recorders were placed alongside each other and were driven by a single motor (to ensure consistent timing). A transmission was made from one of the recorders every $\frac{1}{3}$ second, so that within one second a signal was made with each of the three frequencies through three inductive chargers. Received signals were led from the oscillator through an amplifier tuned to the transmitted frequency, and then to the paper recorder. The machine is illustrated in Plate I (*c*).

Besides the paper record, received signals were also presented on an oscilloscope, on which three time-bases were triggered to the transmissions from the recorders. The three time-bases, corresponding to each of the three frequencies, were presented in quick succession on the screen of the oscilloscope at three levels, by changing the voltage on the plates as signals on each frequency were transmitted. The width of the screen could be covered in 15 or 50 milliseconds (ms.), representing 6 and 20 fathoms respectively. Hence any trace could be examined in detail. Furthermore, photographs of the three time-bases were taken, presenting the results on one negative, as if simultaneously. A typical record (50 ms.) is shown in Plate I (*d*).

Signals were measured by comparing them with signals of known voltage injected into the amplifier circuit and photographed in the same way as the original observations. Hence it was necessary that the amplifier remained at the same setting both during the observations and during the injections.

Method

The triple sounder was to be used on an identified fish shoal. Identification may be distinguished as general or particular. A general identification is made by going to a place where a fish species is expected at a particular time, and assuming that all fish traces are attributable to that species; a particular identification is made by catching the fish in the trace as closely to the time of observation as possible. Details of methods of identification will be treated when discussing the results; when fish traces are named as cod or herring, it should be taken that the identification is reliable. When identification has remained uncertain, traces will be referred to as "unidentified", although such evidence as is available on their identity will be presented.

Before each cruise, an engineer from Messrs. Kelvin and Hughes flashed the oscillators and checked the inductive charges. Having reached a favourable place, an echo survey was made with the normal ship's echo sounder. When fish traces were recorded, the oscillator framework was put over the side and secured.

Observations were only made in good weather and when the record of the sea bed was clear and strong. This limit was very necessary because, if the ship rolled, air bubbles could be trapped beneath the oscillator fairing and sometimes no signal was received from the bottom at all. Again, a very rough measure of day to day variations in the instruments on a particular cruise was obtained.

Treatment of Results

One of the difficulties in using a cathode ray presentation of echo-sounding records lies in the distinction between noise and fish shoals; this really is resolved in the consistency of the signals returned from fish shoals as opposed to the random character of noise. On a paper record, it is done by comparing records over previous minutes (which is difficult with a CRO) and adjusting the amplifier setting until the paper is clean (or perhaps slightly noisy) and fish traces emerge dark and consistent. With the triple sounder a further device was used in that, before use, the set was switched on and, without transmission, the amplifier setting was reduced until the time-bases remained clear. However, from examination of all records, it appears that some noise remained on 10 kc/s; this is not unexpected, but in analysing each record, it presents certain difficulties. These were not resolved, and it will be seen that to a small extent the 10 kc/s results, and to a slight extent those on 14 kc/s, are overestimated. It is not considered that these errors, in any one case, exceed the quoted variances.

The measurement of signals was carried out in the following way. Film records were projected with a Leitz film projector and the outline of each record was traced on paper. Injected signals were treated in the same way. For any one series of observations, a graph was prepared relating the amplitude of the injected signal in microvolts (μv.) to its amplitude as measured in centimetres (cm.) on the projection of the film record on paper; the amplitude in μv. was plotted on the ordinate and the projected amplitude in cm. was plotted on the abscissa. Linear extrapolation of the graph made an intersect on the abscissa and it was assumed that this intersect was equivalent in cm., projected, to the width of the time-base. Estimated in this way, the time-base was drawn in, on the projected records.

Each projection was divided into sections up from the record of the sea bed; each section corresponded to 5 m. of depth in the sea on a 50 ms. record. They were named A, B, C, D, E and F, reading up from the record of the sea bed. The area of each section above the estimated time-base was measured using a planimeter; both positive and negative amplitudes were measured and a mean taken of the two measurements. Signals were then expressed as cm.^{2} of projected section.

From the measurements, expressed as cm.^{2} of projected section, square roots were extracted, giving an average amplitude in cm. for each projected section. The graph of *μv. injected* on *cm. amplitude projected* was then used to convert the average amplitudes into

μv. We have, then, average amplitudes in μv. for sections of 5 m. in depth and for three frequencies.

The number of observations in any one series varied between 4 and 26. Means and standard deviations were extracted from the whole series in sections; both means and standard deviations were then divided by the relative calibration values, which were as follows:

10 kc/s	14 kc/s	30 kc/s
4·25	1	2

A coefficient of variation was extracted for each series of observations at all depths and for each frequency; examination of means and standard deviations will show that this simplification is, in most cases, not unreasonable. For all observations on one fish species at one frequency, a mean coefficient of variation was extracted, using the following formula,

$$\frac{\sqrt{\frac{\left[\Sigma x_1^2 - \frac{(\Sigma x_1^2)}{n_1}\right] + \left[\Sigma x_2^2 - \frac{(\Sigma x_2)^2}{n_2}\right]}{n_1 + n_2 - 2}}}{\frac{\Sigma x_1 + \Sigma x_2}{n_1 + n_2}} \cdot 100$$

where $x_1, x_2, \ldots . x_n$ are the observations in each section of depth.

Results are presented in Tables I, IV, V, VII and X as average amplitudes on each frequency, for each 5 m. section of depth. Each Table is divided into sections each including one set of observations, e.g., E.H. 2, 107–112; this set of observations included frames 107–112 from the second reel of film taken on the ERNEST HOLT.

RESULTS

Cod (Bear Island)

Off Bear Island in June, a cod fishery occurs which varies in position, from the North West Gully round to the South East Gully, and in depth from 65–110 fms. In June 1952, a number of trawlers of different nationalities were in sight most of the time; from their

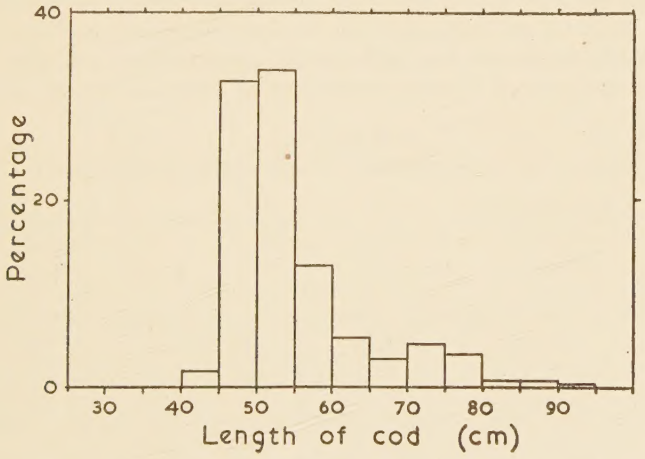

FIG. 1. Percentage length-distribution of cod, ERNEST HOLT, Cruise IV, 1952

wireless reports, they were catching cod exclusively. Catches were fairly high (approximately 100 baskets per hour) and a marked proportion of each catch had to be rejected as being undersized. The mean length of fish was 54·2 cm. in the area from which most of the records were taken; the distribution of sizes is shown in Fig. 1. Individuals of other

fish species than cod were caught now and again, but it would be true to say that catches by the ERNEST HOLT were nearly always composed exclusively of cod. On a few occasions a cover was used on the trawl, but no fish other than cod was caught. The fish did not often have food in their stomachs (except on one occasion when capelin were found).

During the cruise, three types of echo trace were recorded on the MS 21 b (used on a 10 kc/s oscillator), as follows:

(*a*) large, irregular masses extending up to 40 fms. from the bottom.
(*b*) fairly dense masses at 100 fms. in midwater over the N.W. Gully.
(*c*) rather thin extensive layers within 10 fms. of the bottom. This trace was sometimes tenuous and masked by the noise associated with the towing of the trawl.

The first and last types of trace were identified as cod traces and it was on the last type that all the triple sounder work was carried out. Because the triple sounder was considerably less powerful than the ship's ordinary sounder, the last type of trace was only shown sporadically on the paper record of the triple sounder; it was, however, always recorded on the CRO and on the MS 21 b.

The general identification that cod were usually caught near Bear Island in June was supported by the fact mentioned above that the ERNEST HOLT and other trawlers in the vicinity caught very little else but cod during the whole period. The particular identification of each trace observed was facilitated by the fact that the ship was on a cod marking cruise. The main trawl was towed for one hour and during this time the record of the MS 21 b was examined for fish traces. After the trawl was brought inboard, fish were put in tanks for up to one hour to sort out the lively ones. During this period, the triple sounder was put over the side and observations were made. Thus, if a trace was observed during trawling and the trawl, when hauled, was full of cod, observations were made on the same trace within ten minutes of the trawl having come inboard.

It should be mentioned that on one occasion a few capelin were found in cod stomachs. These fish are not caught by the main trawl. However, when echo traces have been identified as capelin, they occurred extensively in the midwater (personal communication, J. Tchernia and R. J. H. Beverton). It is thought unlikely that capelin contributed to the formation of the majority of echo traces examined.

Results from the ERNEST HOLT observations are presented in Table I, showing the average amplitude as μv. per section of depth for each frequency for each series of observations. The standard deviations for each set of observations are also given; these are summarized in the estimate of a mean coefficient of variation for all observations at one

TABLE I

Average amplitudes, for three frequencies, on cod traces, ERNEST HOLT, Cruise IV, 1952

Records ..	E.H. 2,107–112	E.H. 3,8–31
Depth of trace	60 fms.	65–80 fms.
Bottom ..	72 fms.	83 fms.
Writing speed	50 ms.	50 ms.
Number of observations	6	17

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	1·252 ± 0·237	4·100 ± 1·228	4·316 ± 0·258	3·260 ± 1·167	10·706 ± 1·955	1·576 ± 0·462
B ..	0·485 ± 0·110	2·350 ± 0·554	0·608 ± 0·625	3·056 ± 1·327	10·171 ± 2·841	1·509 ± 0·724
C ..	0·513 ± 0·092	3·017 ± 1·612	0·900 ± 0·565	3·360 ± 1·120	10·129 ± 2·555	1·641 ± 0·462
D ..	0·541 ± 0·168	2·817 ± 0·904	0·892 ± 0·585	2·811 ± 0·896	10·641 ± 2·393	1·738 ± 0·480
E ..	0·494 ± 0·067	2·667 ± 0·625	1·484 ± 0·316	2·363 ± 1·168	10·241 ± 2·362	1·624 ± 0·602
F ..	—	2·740 ± 0·969	1·650 ± 0·304			
C.V.	22·511%	35·481%	29·386%	38·523%	23·495%	34·366%

	E.H. 3,45–77	E.H. 3,94–128
Records	E.H. 3,45–77	E.H. 3,94–128
Depth of trace ..	70–80 fms.	60–70 fms.
Bottom	70 fms.	70 fms.
Writing speed ..	50 ms.	15 ms.
Number of observations	18	26

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	1·102 ± 0·215	8·200 ± 4·122	0·811 ± 0·738	1·051 ± 0·542	10·050 ± 4·264	1·154 ± 0·432
B ..	0·980 ± 0·209	7·600 ± 3·426	0·564 ± 0·687			
C ..	1·025 ± 0·252	8·889 ± 4·021	0·747 ± 0·642			
D ..	1·114 ± 0·256	9·600 ± 3·210	0·442 ± 0·694			
E ..	1·042 ± 0·300	7·522 ± 2·241	0·722 ± 0·458			
F ..						
C.V.	23·626%	41·503%	99·034%	51·557%	42·430%	37·379%

	E.H. 4, 10–13	E.H. 4, 23–39
Records	E.H. 4, 10–13	E.H. 4, 23–39
Depth of trace ..	60–65 fms.	55–60 fms.
Bottom	65 fms.	65 fms.
Writing speed ..	50 ms.	50 ms.
Number of observations	4	15

	10 kc/s	14 kc/s	* 30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	1·888 ± 0·192	5·125 ± 0·943	0 0	0·897 ± 0·681	9·853 ± 3·150	0·470 ± 0·973
B ..	2·088 ± 0·261	6·375 ± 1·266	0 0	1·043 ± 0·356	8·160 ± 3·490	0·290 ± 0·632
C ..	2·141 ± 0·216	5·925 ± 0·519	0 0	0·960 ± 0·286	9·573 ± 4·168	0·394 ± 0·974
D ..	1·824 ± 0·182	4·900 ± 0·993	0 0	0·849 ± 0·364	10·087 ± 3·628	0·110 ± 0·426
E ..	2·241 ± 0·106	6·575 ± 0·802	0 0	0·919 ± 0·277	9·247 ± 2·532	0·630 ± 1·176
F ..	0·806 ± 0·116	5·400 ± 1·849	0 0			
C.V.	9·705%	19·961%		45·150%	36·622%	232·017%

	E.H. 5, 3–16	E.H. 5, 60–81
Records	E.H. 5, 3–16	E.H. 5, 60–81
Depth of trace ..	65–85 fms.	60 fms.
Bottom	85 fms.	65 fms.
Writing speed ..	50 ms.	50 ms.
Number of observations	9	16

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	0·821 ± 0·155	6·367 ± 5·197	0·384 ± 0·667	1·953 ± 0·709	9·200 ± 4·122	1·222 ± 0·574
B ..	0·829 ± 0·429	5·778 ± 4·364	0·444 ± 0·540	1·699 ± 0·549	7·719 ± 3·104	1·284 ± 0·413
C ..	0·818 ± 0·175	6·938 ± 5·452	0·412 ± 0·444	1·734 ± 0·484	7·838 ± 2·948	1·269 ± 0·554
D ..	0·880 ± 0·222	5·438 ± 5·330	0·825 ± 0·403	1·827 ± 0·390	9·694 ± 3·547	1·247 ± 0·510
E ..	1·024 ± 0·253	5·288 ± 4·210	0·806 ± 0·454	1·987 ± 0·538	8·825 ± 3·182	1·481 ± 0·550
F ..				1·676 ± 0·662	8·719 ± 3·041	1·419 ± 0·458
C.V.	30·846%	82·632%	91·062%	31·191%	38·639%	38·843%

μv./section and S.D.
mean coef. variation } calibrated

* Observations in this series at 30 kc/s were too small to be measured.

frequency in each series. Taking the observations in section A only, which is the only section in depth identified by the trawl, it will be noticed that signals received on 14 kc/s were between 3 and 10 times greater than those received on 10 kc/s and up to 20 times greater than those received on 30 kc/s. One anomalous observation occurred on the 30 kc/s series, when the signals were equivalent to those received on the 14 kc/s set [E.H.2, 107–12]; it was at this station that capelin were found in cods' stomachs, suggesting that perhaps a mixture of the two species was contributing to the echo trace.

Examination of the means of observations and their standard deviations makes it clear that there are significant differences between signals on 14 kc/s and 10 kc/s on the one hand, and between 14 kc/s and 30 kc/s on the other; such differences between signals on different frequencies are expressed as ratios of signals at one frequency to those at another (frequency ratios), using 10 kc/s signals as unity; it was not considered worth analysing these differences in detail further, because a single observation might well be related to an odd shoal of rather larger cod swimming beneath the echo sounder, twenty minutes after the measured fish had been brought aboard. Frequency ratios for each set of observations for section A are shown in Table II.

TABLE II

Frequency ratios for each set of observations for Section A, ERNEST HOLT, Cruise IV, 1952

10 kc/s	14 kc/s	30 kc/s
1	3·3	3·4
1	3·3	0·5
1	7·4	0·7
1	9·6	1·1
1	2·7	0
1	11·0	0·5
1	7·8	0·5
1	4·7	0·6

It was noticed that between series of observations at the bottom (section A), there were significant differences at one frequency and small differences in frequency ratios. In depth, however, differences at one frequency for any one series of observations were very small indeed. On 14 kc/s, there are no differences between observations at different depths for any one series; on 10 kc/s, 2 observations out of 37 are significantly different from the mean of a depth series; on 30 kc/s, 3 out of 38 are different and these are all found in the one series (E.H. 107–112), where it is possible that some capelin were present. Thus, within 30 m. of the bottom, there is no difference in returned signal at any one frequency (Fig. 2) and there is no difference between the frequency ratios. This implies that the shoals are very consistent in shoaling density and in size composition at different depths. The differences, however, between series of observations, which are of course horizontal differences, are large. If we assume that a difference in frequency ratio implies a difference in size of fish, as will later appear, it seems likely that the fish are, in general, shoaling consistently by size.

As with the means of the observations at different depths, so is there no trend of standard deviation with depth; therefore standard deviations may be compared between frequencies and between depths. Coefficients of variation, are set out in Table III for each frequency and for each series of observations. The mean coefficient of variation is calculated by the method given above under *Treatment of Results.*

Herring (*Sandettié*)

Since 1950, German, Dutch, Belgian and French herring trawlers have worked in the narrow stretch of water between the Sandettié and Ruytingen Banks in November, December and January. Dense and extensive echo traces have been recorded in this

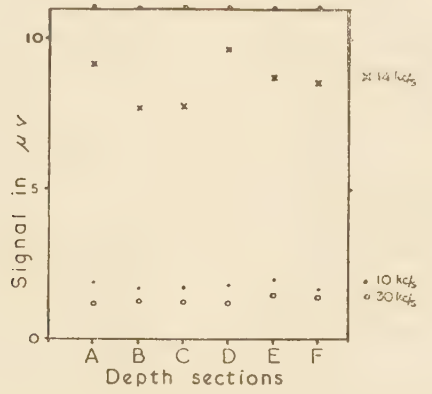

FIG. 2. Constancy of signal amplitude at different depths, ERNEST HOLT, Cruise IV, 1952. (E.H.5, 60-81)

fishery and they have always been referred to the herring that has been caught there in such large quantities (German trawlers alone caught 44,000 tons there in 1952–3). Like most trawled herring fisheries today, this is an echo-sounder fishery, i.e., skippers shoot on echo traces and rely on them.

TABLE III

Coefficients of variation (as percentages) for each series of observations at each frequency for ERNEST HOLT, Cruise IV, 1952, on fish identified as cod.

	10 kc/s	14 kc/s	30 kc/s	n
	23	35	29	6
	39	23	34	17
	24	42	99	18
	52	42	37	26
	10	20	—	4
	45	37	232	15
	31	83	91	9
	31	39	39	16
mean	40	40	62	

The echo traces that were found in this region in 1952 were of two types. In the daytime, they were dark, quite wide (15–20 soundings), and extensive in depth although they did not reach the bottom; the depths of the tops of the shoals generally varied between 8 and 12 fms., although a few lay more deeply and some lay in shallower regions. At night, the traces were of quite a different nature; in fact, on one night, their diffuseness led us to believe that perhaps we were not receiving signals from fish at all. The most prominent feature of the trace was its extensiveness: we steamed for seventeen miles and found no change in the record, the whole paper from surface to bottom being covered with a rather diffuse and characterless trace.

We made sure that the trace was composed of fish in the following way. The ship was stopped and the Aldis lamp (10-in. diameter) was shone over the side (the deck lights had been darkened for some time). As shown in Plate II (*a*), the fish reacted immediately. It is interesting to see that they gathered again at the range of a moderate light intensity; it

is also interesting to note that the noise of the ship's engine starting had a similar shock effect on the fish's behaviour [Plate II (*b*)].

During the day about a dozen German trawlers were working, catching herring in rather small quantities, about 20–30 baskets in each haul. From Sir Lancelot a herring trawl was also worked in the daytime and only herring were caught (in very small quantities). At night the herring trawl, being a bottom gear, caught nothing. However, a few pair-trawlers were working at night in this region, catching herring. The triple sounder was worked at night because the traces were then denser and more consistent; this was done deliberately for that reason. It might well be considered that the difference between the character of the traces in day-time and night-time was a difference associated with different organisms; the Aldis lamp test convinced us that the sound energy was returned to the oscillators by fish, for only fish could move so rapidly. The fact that this trace at night-time extended continuously from surface to bottom for seventeen miles at least, led us to believe that only herring were numerous enough to have produced the trace. Again, Skipper George Leslie has told me that herring, as caught by the M.V. Betty Leslie, responded to the noise of the engines; his record shows that they did so to the same degree as shown in Plate II (*b*). Although the night-time traces were not rigorously identified as herring, the identification is reasonably clear.

Observations on this herring trace were of two types (see Table IV). In one set (Sir Lancelot 4), frequency ratios were constant with depth; in the other (Sir

Table IV

Average amplitudes, for three frequencies, on herring traces, Sir Lancelot, Cruise III, 1952

Records	S.L. 3, 30–49	S.L. 4, 1–9
Bottom	21 fms.	21 fms.
Writing speed ..	50 ms.	50 ms.
Number of observations	17	9

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A	2·994 ± 0·301	16·276 ± 7·463	38·086 ± 6·690	4·946 ± 0·428	17·589 ± 2·682	30·516 ± 4·544
B				6·160 ± 0·259	17·933 ± 1·724	33·044 ± 2·293
C				7·642 ± 0·734	21·100 ± 2·516	36·716 ± 1·850
D				8·424 ± 0·929	26·422 ± 2·018	44·566 ± 4·338
E				10·854 ± 1·256	30·733 ± 1·722	52·961 ± 4·036
C.V.	10·044%	45·853%	17·566%	10·413%	9·535%	9·074%

	S.L. 4, 12–24 21 fms. 50 ms. 10			S.L. 3, 1–19 21 fms. 50 ms. 16		
	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A	4·508 ± 0·526	35·020 ± 4·778	76·210 ± 11·716	3·403 ± 1·061	10·706 ± 2·681	0 0
B	6·831 ± 0·535	43·590 ± 7·312	114·570 ± 9·411	5·896 ± 0·761	14·431 ± 1·895	16·450 ± 15·922
C				9·954 ± 0·531	17·044 ± 1·449	69·050 ± 8·101
D				9·499 ± 1·323	13·744 ± 3·289	83·406 ± 7·836
E				7·745 ± 0·656	2·243 ± 3·872	110·631 ± 7·933
C.V.	9·356%	15·713%	11·140%	12·628%	23·125%	16·846%

μv./section and S.D. } calibrated
mean coef. variance }

PLATE I(*a*). The three oscillators of the triple sounder

The oscillators are mounted in a wooden fairing at the end of the tubular steel framework.

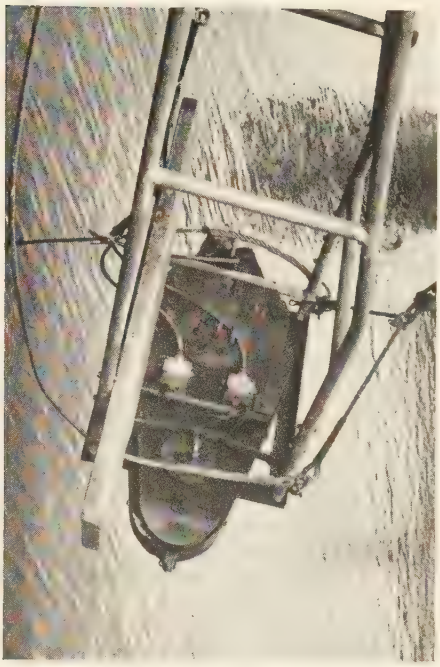

PLATE I(*b*). The oscillator framework mounted on the rail of the ERNEST HOLT

The three transceiver cables are seen inside the framework. The three holes on the rail brackets can be seen, the centre one holding the pivoting pin, the inboard one holding the securing pin and the outboard one empty. When the securing pin is taken out, the framework can be pivoted over the side and resecured in the bracket, with the securing pin in the outboard position.

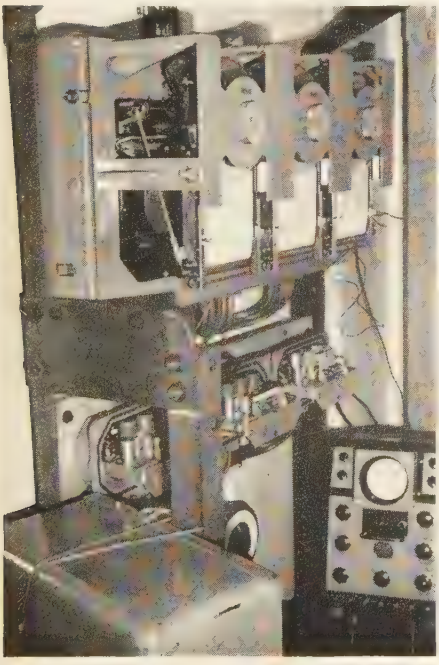

PLATE I(*c*). The triple sounder recorder mounted in the ERNEST HOLT

In addition to the recorders, the signal injector and the oscilloscope are shown below.

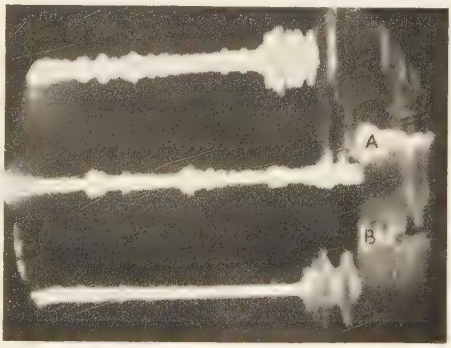

PLATE I(*d*). A typical triple sounder photographic record

The strong record of the bottom is shown at the right of each record. Fish shoals are shown on the time base to the left of the bottom signals, i.e. just above the bottom. The white portions of the bottom records on 14kc/s at A and on 30kc/s at B are probably a consequence of a short persistence of the screen as the 10kcs signal is recorded first.

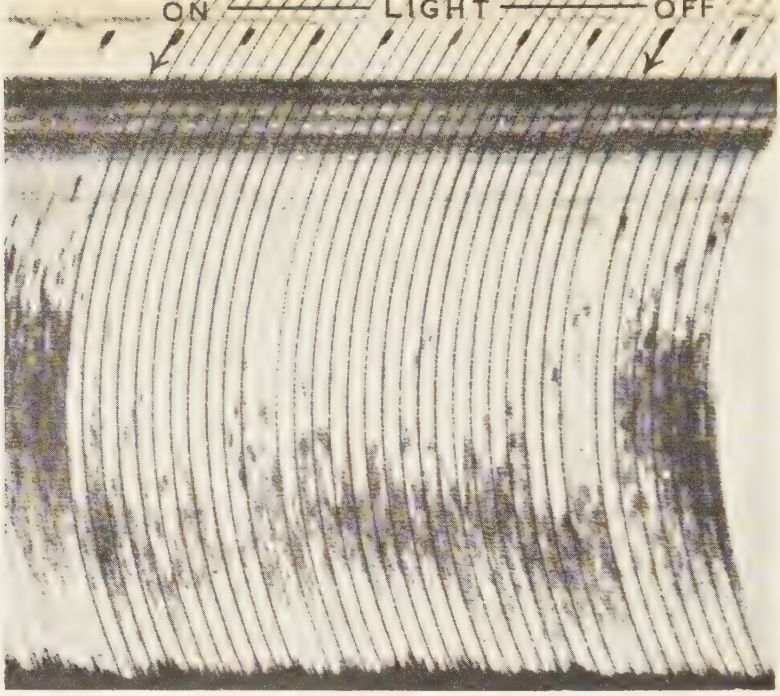

PLATE II(*a*). An echo trace of fish shoals responding to a sudden change in light intensity
The ship was stopped. At " on ", an Aldis lamp (10 in.) was switched on and shone down from the ship with the decklights off. The marker has been used to make 30 second intervals on the record paper. It will be noticed that the reaction to the change in light intensity is immediate. (MS 26*b*, teledeltos paper, at Sandettié.)

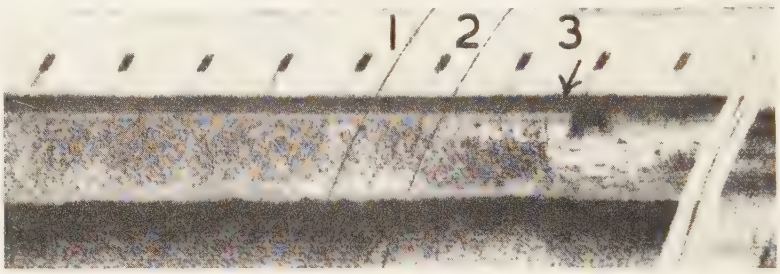

PLATE II(*b*). An echo trace of fish shoals responding to the noise of the propeller
The marker lines show (1) where the ship's engines were stopped, (2) where she turned, (3) where the engines were put astern. The dark mass at the surface, a little later, is due to a mass of air bubbles. Note the response of the organisms producing the echo trace, to the noise of the engine, and note their gradual return after the engine had stopped. (This trace was recorded at Sandettié at night ; it extended for at least 17 miles N.E. from the Sandettié buoy. The character was always the same as shown in this figure; it will be noticed that the trace tends to be clear of the bottom and densest in midwater. MS 26*b*.)

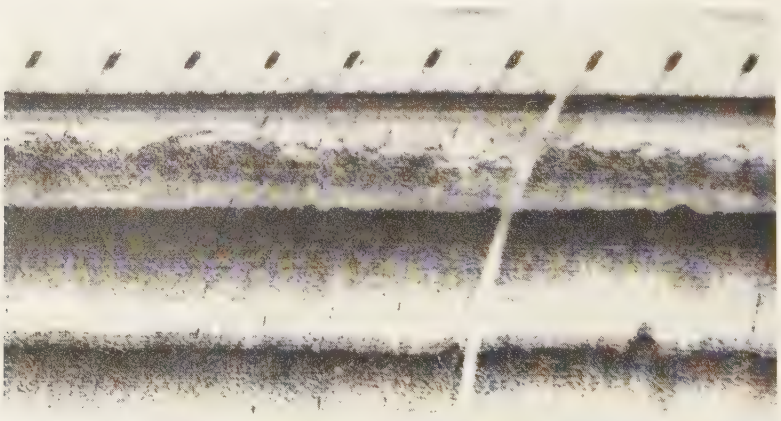

PLATE II(*c*). The Sandettié trace SIR LANCELOT, Cruise III, 1952
The trace is a little different in character from that in Plates II(*a*) and II(*b*), being taken on a different night, but shows the same characteristic features. (MS 26*b*.)

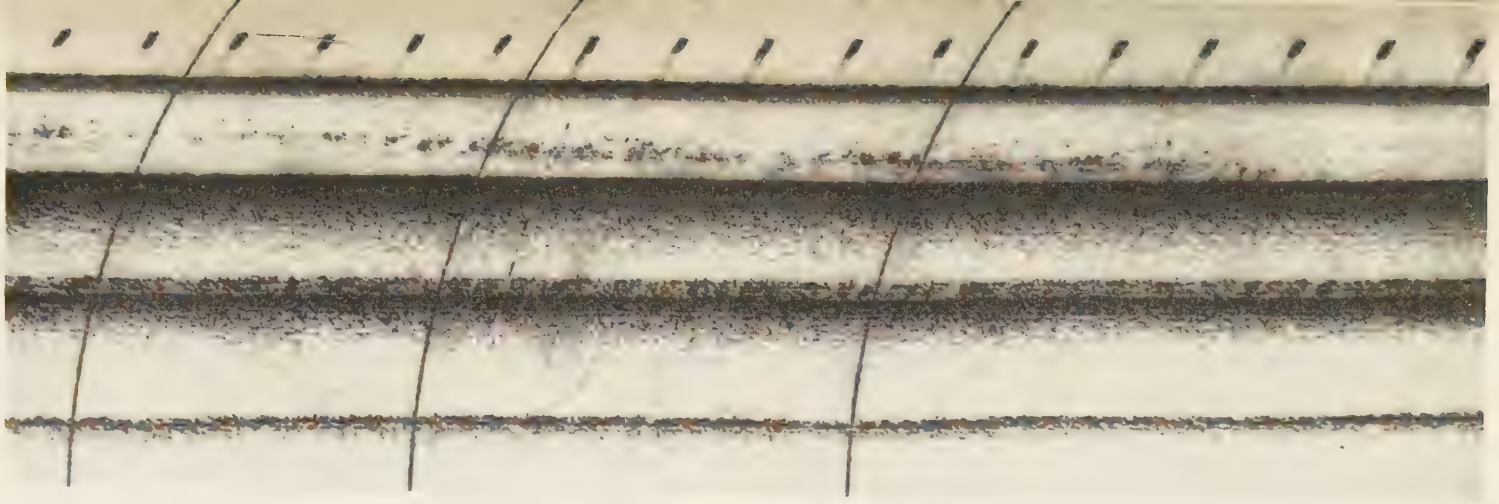

PLATE III(*a*). The Ruytingen trace at dawn
A somewhat diffuse character changes to a stronger, more aggregated type of trace as the light increases. (MS 26*b*.)

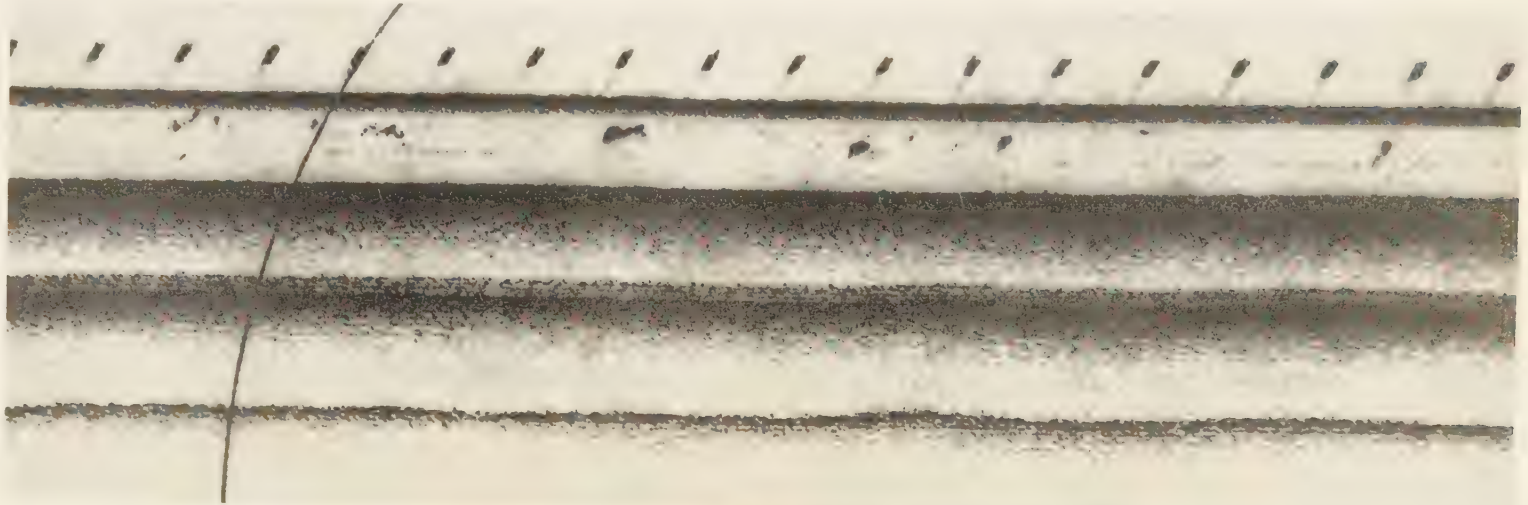

PLATE III(*b*). Daytime traces at Sandettié identified as herring
The dark, discrete character and the variation in depth are characteristic of herring at this season. (MS 26*b*.)

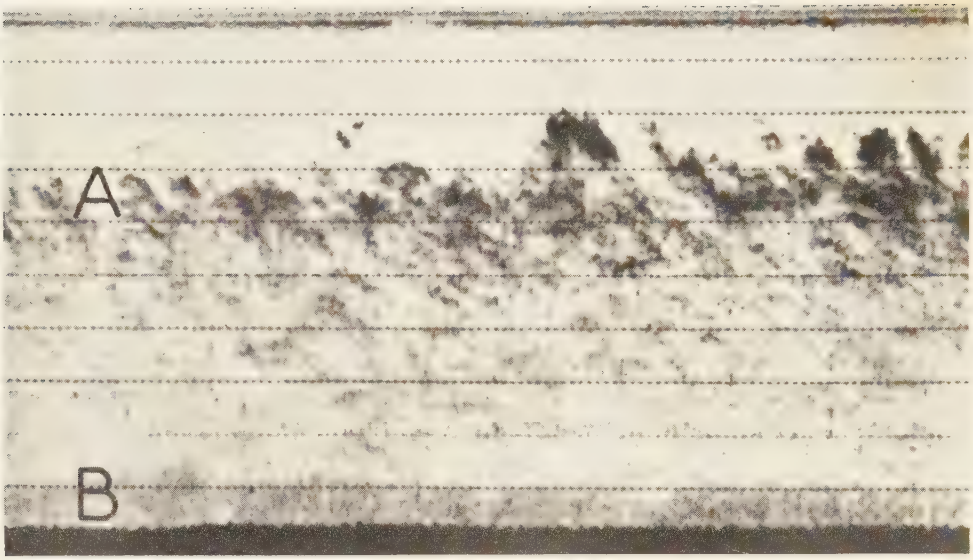

PLATE IV(*a*). The Start Point traces at night
The extensive midwater traces, A, were identified as pilchards and the diffuse bottom trace, B, was not identified. (Seagraph.)

PLATE IV(*b*). The " bottom diffuse layer " in daytime
Note the aggregated character of the trace in daylight, as opposed to the diffuse character of the bottom trace in Plate IV(*a*). (MS. 26*b*.)

Lancelot 3), these ratios varied with depth. Taking the first set, strongest signals were returned on 30 kc/s, by nearly three times; the second set, however, is illustrated in Fig. 3, in which the μv. per section is plotted against sections, or depth. Not only does the frequency ratio change violently with depth, but also the signals on the 30 kc/s receiver increase many times in 20 m. The fish shoals that attracted attention were midwater ones [Plate II (*c*)], which would account for the strong signals received on 30 kc/s in section C–E. In sections A and B, however, signals were weak and the frequency ratios were not unlike those obtained on cod off Bear Island. It seems possible that herring were present in the midwater and that perhaps some larger fish was present in small numbers near the bottom; the frequency ratios in the midwater resemble those found in Sir Lancelot 4. If this interpretation is true, it is difficult to see how confirmatory identification could be made at all depths at the same time; if frequency ratio is truly a function of size, the triple sounder has a high degree of discrimination that can only be confirmed indirectly.

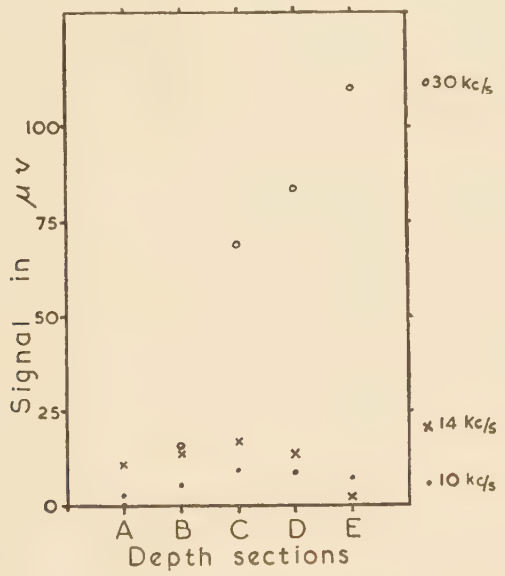

Fig. 3. Signal amplitudes at different depths, Sir Lancelot, Cruise III, 1952. (S.L. 3 1-19)
There are marked differences in amplitude at different depths for the signals on 30 kc/s.

Taking the observations in Sir Lancelot 4 and C–E in Sir Lancelot 3, the frequency ratio is about 3:1 from 14 kc/s to 10 kc/s and again 3:1 from 30 kc/s to 14 kc/s; the mean coefficients of variation are 10% (10 kc/s), 21% (14 kc/s) and 11% (30 kc/s). The full results are given in Table IV.

Herring (*Northumberland*)

Cruise XIV Sir Lancelot was carried out in July 1952, within the region that was being worked by Dutch trawlers and drifters off the coast of Northumberland. By going to this region we were intending to find herring and the fish are often recorded on echo sounders as thick heavy traces lying near the bottom in the daytime and coming up to about 10 fathoms at night.

Particular identification of the traces examined was made by observing the catches of herring by trawlers in the daytime.

Table V gives the signals, received on each of the three oscillators, with their errors, and the mean coefficient of variation for each series at each frequency. Comparison of signals on the three receivers shows that the strongest signals were received on the 30 kc/s

TABLE V

Average amplitudes, for three frequencies, on herring traces located off the Northumberland coast, SIR LANCELOT, Cruise XIV, 1952

	S.L. XIV, 13–22			S.L. XIV, 29–35			S.L. XIV, 43–57		
Records	40 fms.			38 fms.			40 fms.		
Bottom	15 ms.			15 ms.			50 ms.		
Writing speed ..	10			7			15		
Number of observations									
	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	0·506 ± 0·210	3·380 ± 2·340	5·825 ± 3·470	0·431 ± 0·454	1·600 ± 1·365	2·385 ± 2·860	0·172 ± 0·198	1·090 ± 0·302	2·235 ± 1·025
B ..							0·835 ± 0·885	2·370 ± 1·958	3·880 ± 2·246
C ..							1·471 ± 0·942	2·880 ± 1·616	5·540 ± 2·902
D ..							1·993 ± 1·733	4·970 ± 3·671	11·440 ± 8·228
C.V. ..	41·581%	69·231%	59·571%	105·577%	85·312%	119·912%	97·178%	79·102%	78·523%

	S.L. XIV, 64–72			S.L. XIV, 73–80		
Records	40 fms.			40 fms.		
Bottom	15 ms.			50 ms.		
Writing speed ..	9			8		
Number of observations						
	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	0·607 ± 0·340	1·940 ± 0·482	13·970 ± 1·860	1·151 ± 0·032	1·360 ± 0·177	10·625 ± 3·399
B ..						
C ..						
D ..						
C.V. ..	56·129%	24·794%	13·312%	2·782%	12·996%	31·991%

μv./section and S.D. } calibrated
mean coef. variation }

oscillator; the frequency ratios are of the same order as those found on herring at Sandettié. Most signals were received from a layer near the bottom; on the one occasion when a depth series of observations was made, marked differences in the magnitude of signals with depth were found. No differences, however, in frequency ratio were found. This implies that there was no mixture of other fish with the herring and that there were many more fish 20 m. off the bottom than close to it.

The coefficients of variation are widely variable, from 3–120%. As the variability is similar at each of the three frequencies for any one series, and is found between the series, there is no point in extracting mean coefficients of variation. Table VI shows the coefficients from observations taken on Cruise XIV, Sir Lancelot, 1952.

However, an average coefficient of variation would not be far from 75 per cent on all three frequencies. Comparing this value with that found on herring at Sandettié (10-21%), it will be seen that there is a very marked difference between the Sandettié and Northumberland observations, but there is no difference in frequency ratio. This must reflect differences in behaviour; perhaps the fish at Sandettié were packed more uniformly than those off Northumberland. The Sandettié shoals are in general at a later stage of maturity than those off Northumberland in July; in fact, the latter may be to some extent still feeding.

Table VI

Coefficients of variation (as percentages) for each series of observations at each frequency taken on herring for Sir Lancelot, Cruise XIV, 1952

10 kc/s	14 kc/s	30 kc/s	n
42	69	60	10
106	85	120	7
56	25	13	9
97	79	79	15
3	13	32	8

unidentified trace at Ruytingen

At night, between the Ruytingen Bank and the Dyk L.V., a trace was observed on the echo sounder record in the midwater. Observations were made on it because it was assumed, before identification was considered, that the fish producing the trace were herring. As dawn broke, however, doubt was cast on this general identification, because as the light came into the sky, the trace took on the character of a descending layer, which reached the bottom by the time the sun came up. This character in day-time is quite different from that of herring. The Ruytingen trace is illustrated in Plate III (*a*), whereas Plate III (*b*) shows typical herring traces found at Sandettié during the day-time. The Ruytingen trace remained as a layer, diffuse and continuous, near the bottom, when herring traces at the same time were dark, compact, discrete and not limited to one depth. Whilst the observations with the triple sounder were being made, light measurements were also being made at as short time intervals as possible with a photomultiplier cell; this apparatus will be described elsewhere, but it may be stated here that the Ruytingen trace remained at one light intensity level, i.e., 10^{-4} — 10^{-5} foot candles. The same gear has also shown recently that herring shoals in day-time in this region are found at a wide range of light intensities (10^{2} — 10^{3} foot candles). Again, Richardson (1952) has shown that the day-time depth of herrings in this region varies from 5–12 fms., whereas the Ruytingen trace remained on the bottom in day-time. It seems reasonable to conclude that the Ruytingen traces were not produced by herrings. No closer identification was possible, because we were unable to trawl in this position; small boats from Calais, however, were catching whiting nearby, although not near enough for us to claim an identification.

Four sets of observations were made in section A only (see Table VII); three sets were made in two or three sections, and, of the latter, frequency ratios are constant with depth,

Table VII

Average amplitudes for three frequencies on an unidentified fish trace, Sir Lancelot, Cruise XX, 1952

	S.L. 1, 1–12	S.L. 1, 23–33
Records	S.L. 1, 1–12	S.L. 1, 23–33
Bottom	18 fms.	18 fms.
Writing speed ..	50 ms.	15 ms.
Number of observations	7	11

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	4·180 ± 0·731	16·957 ± 2·747	19·443 ± 3·527	12·888 ± 3·003	85·682 ± 10·682	51·004 ± 4·054
B ..						
C ..						
C.V.	17·475%	16·200%	18·140%	23·298%	12·467%	7·948%

	S.L. 1, 49–57	S.L. 1, 68–79
Records	S.L. 1, 49–57	S.L. 1, 68–79
Bottom	14 fms.	14 fms.
Writing speed ..	15 ms.	15 ms.
Number of observations	10	9

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	3·544 ± 0·526	60·370 ± 8·061	22·835 ± 3·054	5·919 ± 0·701	107·378 ± 43·311	27·661 ± 1·978
B ..						
C ..						
C.V.	14·852%	13·352%	13·372%	11·841%	40·335%	7·149%

	S.L. 1, 83–92	S.L. 2, 1–20	S.L. 2, 30–49
Records	S.L. 1, 83–92	S.L. 2, 1–20	S.L. 2, 30–49
Bottom	16 fms.	16 fms.	18 fms.
Writing speed ..	50 ms.	50 ms.	50 ms.
Number of observations	9	18	19

	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s	10 kc/s	14 kc/s	30 kc/s
A ..	3·043 ± 1·316	48·989 ± 48·370	21·584 ± 4·930	4·378 ± 0·618	48·694 ± 18·518	12·906 ± 2·744	0·567 ± 0·699	42·000 ± 15·684	2·792 ± 4·528
B ..	1·187 ± 1·136	66·511 ± 44·971	30·872 ± 9·784	4·111 ± 0·677	56·433 ± 14·583	18·239 ± 3·703	2·115 ± 0·609	49·800 ± 9·741	10·463 ± 6·562
C ..				5·039 ± 2·704	60·156 ± 12·586	26·150 ± 3·912	10·225 ± 1·412	49·200 ± 17·245	25·124 ± 4·127
C.V.	58·142%	80·868%	29·538%	36·557%	28·001%	18·276%	22·668%	31·035%	40·519%

uy /section and S.D.)

except for section A in SIR LANCELOT (2) 30–49, in which the frequency ratios are markedly different from those shown in sections B and C. Excluding all the depth series, signals on 14 kc/s were about ten times as strong as those on 10 kc/s and only twice as strong as those on 30 kc/s. Standard deviations in this series of observations are not so consistent as the ones previously considered; those for SIR LANCELOT (1) 1–79 are reasonably consistent, but in SIR LANCELOT (1) 83–92 the standard deviations on all frequencies are much higher. Those in SIR LANCELOT (2) are very variable; rather than extract a mean, coefficients of variation are set out separately in Table VIII.

TABLE VIII

Coefficients of variation (as percentages) for each series of observations at each frequency for SIR LANCELOT, Cruise XX, 1952

10 kc/s	14 kc/s	30 kc/s	n
17	16	18	7
23	12	8	11
15	13	13	10
12	40	7	9
58	81	30	9
37	28	18	18
23	31	41	19

Taking observations from SIR LANCELOT (1) 1–79 only, the mean coefficients of variation were 25% (10 kc/s), 32% (14 kc/s), and 10% (30 kc/s). The sudden increase in variability when frequency ratios remained the same could possibly be explained if fish of the same size started to shoal in a different manner, perhaps, for example, swimming in shoals that were much further apart. It is interesting to notice that the first four observations were carried out in full darkness and that the last three were made as light was increasing. Perhaps in darkness, signals were being received from fish scattered fairly uniformly, but in the dawn signals were being received from shoals, the fish having formed up as the light increased.

unidentified trace at Start Point

Cruises undertaken in the English Channel by SIR LANCELOT in the summer of 1950 (Cushing, in preparation) showed that pilchards, as indicated by the presence of their eggs, were concentrated in April between Start Point and Land's End. A combined cruise was arranged with SIR LANCELOT and PLATESSA; PLATESSA was to survey the region and find echo traces identifiable as pilchards and SIR LANCELOT was to rendezvous with PLATESSA at a suitable point.

After a survey PLATESSA found extensive traces in the midwater about 15 miles off Start Point. There were two types, a well marked broken trace (A) at 8–12 fms. and a diffuse continuous trace (B) on the bottom. [See Plate IV (*a*).] It was thought that one of these traces was composed of pilchards, because very high catches of pilchard eggs were found in the region; as pilchard eggs hatch in 48 hours at 14° C, the parent fish were not likely to be very far away. A Larsson trawl was towed at night through the midwater trace at eight fathoms and pilchards were caught; this was repeated and some pilchards were always caught. Shots made at night elsewhere in water with no echo traces yielded no pilchards.

SIR LANCELOT made rendezvous with PLATESSA on the night of 17th April, 1952. However, with much search PLATESSA was unable to find the extensive pilchard traces; this is perhaps related to a severe and extensive thunderstorm that took place over Devon that night. SIR LANCELOT then made observations on the unidentified bottom trace. PLATESSA made an attempt to identify it. The only trawls available were the light Dutch trawl and the Larsson trawl, neither of which we would risk on an unknown sea bed. A Petersen Young Fish trawl was used, because we thought that perhaps the bottom trace, from its

appearance, was produced by fish larvae (not necessarily pilchards, because the behaviour of the pilchard larvae scattering layer is quite different, the layer rising to the surface at night; Burd and Lee, 1951). At night, three hauls were made in the midwater, 20–30 m. above the bottom and three hauls were made on the bottom, or within 5 m. of it. The results are shown in Table IX.

TABLE IX

Numbers of macroplankton per 20 min. haul with a Petersen Young fish trawl, taken in the bottom layer and in the midwater, off Start Point, April 17, 1952.

Species	Bottom hauls			Total	Midwater hauls			Total
Amphipods	9	26	56	91	4	—	5	9
Isopods	2	—	13	15	5	—	10	15
Cumaceans	3	2	4	9	—	—	—	—
Total	14	28	73	115	9	—	15	24
Mysids	64	68	67	199	80	69	111	260
Euphausiids	3	26	15	44	74	16	4	94
Total	67	94	82	243	154	85	115	354
Fish eggs	1,581	1,479	1,546	4,606	1,565	2,128	524	4,217
,, larvae	12	35	19	66	50	18	8	76
Total	1,593	1,514	1,565	4,672	1,615	2,146	532	4,293
Sagittae	1	66	12	79	59	16	3	78
Copepods	17	91	15	123	131	119	—	250
Total	18	157	27	202	190	135	3	328
Crab larvae	72	624	469	1,165	81	255	103	439
Other decapod larvae ..	55	227	394	676	977	82	35	1,035
Total	127	851	863	1,841	1,058	337	138	1,474

Of the comparisons, there are only two that need be considered. Of amphipods and cumacea, there are about ten times as many in the bottom layer as in the midwater; of crab larvae, there are three times as many in the bottom layer as in the midwater. Grouping these animals together, there would be one animal in each cubic metre, or beneath one square metre of the surface of a conic section of a sound cone, the area of which would be 400 m^2., for the type of echo sounders used, at the depth of observation. Comparable signals were received from 0·11 pilchard larvae per cubic metre (personal communication, A. C. Burd); it seems impossible that so few megalopae could return signals equivalent to those of half as many pilchard larvae, which are endowed with air bladders. (Note: We have assumed that the Petersen Young Fish trawl only catches one-fifth of the fish larvae present because they avoid the net and that megalopae do not avoid such a net.) As SIR LANCELOT steamed away it was found that the bottom layer extended from Start Point to St. Catherine's Point and that in the day-time its character had changed from a diffuse continuous layer to an extended layer of sharp aggregations near the bottom [Plate IV (*b*)]. It is unlikely that a distribution of such extent in distance could be of one fish species; we do not know what the layer was composed of, but we guess that portunid crabs or analogous creatures were the agents returning the signals.

Table X gives the results of the frequency comparison on this layer. No signals were received on the 14 kc/s oscillator that could be adequately distinguished from noise and those on the 10 and 30 kc/s oscillators were not significantly different. All observations were made whilst steaming and under these conditions the 14 kc/s oscillator being in the forward position was often subject to aeration and noise; for these reasons, it is not thought that the lack of signal from the 14 kc/s receiver is significant. One might suggest that the

lack of difference between signals received on 10 and 30 kc/s was related to the sizes of the organisms examined; this would be expected if all organisms were smaller than $\frac{\lambda}{4}$ and were then truly scattering sound back to the receiver. However, signals from the cod of Bear Island also show no difference between signals on 10 kc/s and 30 kc/s. Hence, in the absence of signals on the 14 kc/s oscillator, we can only suggest that possibly we may expect no difference in frequency ratio when scattering takes place. The mean coefficient of variation for 10 kc/s was 54% and that for 30 kc/s was 76%.

TABLE X

Average amplitudes, for two frequencies, on an unidentified trace located off Start Point on SIR LANCELOT, Cruise VII, 1952

Records	S.L. VII, 30–36	S.L. VII, 43–59	S.L. VII, 70–85
Bottom	38 fms.	38 fms.	38 fms.
Writing speed	15 ms.	15 ms.	50 ms.
Number of observations	7	13	16

	10 kc/s	30 kc/s	10 kc/s	30 kc/s	10 kc/s	30 kc/s
A ..	0·736 ± 0·094	1·050 ± 0·570	1·040 ± 0·469	1·660 ± 0·928	1·148 ± 0·365	0·840 ± 0·806
B ..	0·791 ± 0·211	1·100 ± 0·366	1·101 ± 0·539	1·600 ± 1·204	0·527 ± 0·259	1·070 ± 1·051
C ..	1·167 ± 0·286	0·995 ± 0·632	1·165 ± 0·415	1·795 ± 1·474	1·007 ± 0·232	0·655 ± 0·564
D ..	1·068 ± 0·166	1·245 ± 0·942	1·360 ± 0·813	1·950 ± 1·626	1·266 ± 0·261	1·175 ± 1·582
E ..	1·115 ± 0·309	1·505 ± 0·880	1·428 ± 1·143	1·785 ± 1·544	0·889 ± 0·419	1·600 ± 1·927
F ..	1·541 ± 0·759	1·240 ± 0·382				
C.V.	30·510%	57·957%	57·134%	78·145%	32·224%	119·714%

Records	S.L. VII, 96–117	S.L. VII, 153–183	S.L. VII, 200–216
Bottom..	38 fms.	38 fms.	38 fms.
Writing speed	50 ms.	15 ms.	50 ms.
Number of observations	21	25	11

	10 kc/s	30 kc/s	10 kc/s	30 kc/s	10 kc/s	30 kc/s
A ..	1·506 ± 0·561	2·120 ± 0·638	1·031 ± 0·230	6·035 ± 3·258	1·306 ± 0·484	2·660 ± 0·678
B	1·002 ± 0·694	2·100 ± 1·432	1·012 ± 0·448	4·850 ± 2·409	1·186 ± 0·416	1·435 ± 0·276
C ..	0·878 ± 0·376	0·395 ± 0·319	1·339 ± 1·204	4·175 ± 2·658	1·704 ± 0·552	1·105 ± 0·242
D ..	1·165 ± 0·423	0·305 ± 0·143	0·991 ± 0·830	2·835 ± 1·976	2·054 ± 0·802	0·980 ± 0·268
E ..	0·706 ± 0·253	0·590 ± 0·200	1·026 ± 0·638	2·890 ± 2·000	2.656 ± 1·647	1·100 ± 0·322
F						
C.V.	46·197%	65·699%	69·433%	60·204%	49·907%	26·897%

μv./section and S.D.
mean coef. variation } calibrated

DISCUSSION

Results as frequency ratios and mean coefficients of variation (where possible) for each set of observations are given in Table XI.

It is clear from this table that there are significant differences between signals of different frequencies received from the same shoal of fish. This is in accord with experiments carried out by us previously (Cushing and Richardson, 1955). Summarizing these experiments, it was found that from artificial shoals of dead herring, stronger signals were received on 30 kc/s, than on 10 kc/s or 14 kc/s and that from similar shoals of dead cod,

TABLE XI

Frequency ratios (with 10 kc/s values taken as unity) and mean coefficients of variation for a number of fish traces.

	10 kc/s	14 kc/s	30 kc/s	
COD (54 cm.)				
Frequency ratio	1	5·4	0·6	
Coeff. variation	40%	40%	62%	
HERRING (Sandettié)				
Frequency ratio	1	2·9	9·2	
Coeff. variation	10%	21%	11%	
HERRING (Northumberland)				
Frequency ratio	1	2·7	7·0	
Coeff. variation	*	*	*	* about 75%
UNIDENT: (Ruytingen)				
Frequency ratio	1	10·0	4·5	
Coeff. variation	25%	32%	10%	
UNIDENT: (Start Point)				
Frequency ratio	1	?	1·8	
Coeff. variation	54%		76%	

stronger signals were received on 10 kc/s than on 14 kc/s or 30 kc/s; small scale experiments at sea showed that on cod near Bear Island, 10 kc/s was more effective than 14 kc/s and that on herring off Calais, 30 kc/s was more effective than 14 kc/s. Although these results are in the main confirmed by the triple sounder results, it must be pointed out that the triple sounder found that stronger signals from 54 cm. cod were received on the 14 kc/s oscillator and not on the 10 kc/s one. It is possible that this difference is actually related to the size of cod; the fish used in Windermere were 65–70 cm. long and those caught off Bear Island averaged only 54 cm.

The results show not only that there are great differences in frequency ratios for different fish, but that the differences are consistent for any one series of observations. Although we were not able to identify the Ruytingen trace, the frequency ratios for a large number of observations are markedly different from those on any other fish; this is in itself important, but when it is made clear that the fish producing the Ruytingen trace were not herring, then it becomes doubly important. A further point is that the frequency ratios appear to be nearly the same for the same fish species in different fisheries.

The coefficients of variation, however, do not remain so constant. There are significant differences between observations on different fish and even here and there between frequencies. As frequency ratios are presumably a function of the sizes of fish, so the coefficients of variation are probably a function of their behaviour. If big fish were always thinly packed and little fish always thickly packed, the coefficient of variation could be used as useful confirmatory evidence in addition to that from the frequency ratio. However, as there are significant differences between the coefficients on herring in different fisheries, it may be either that the degree of packing of the fish in shoals is variable, or that the Northumberland fish with a high coefficient were in little lumps within a shoal and that the Sandettié fish, with a low coefficient, were more uniformly packed within a shoal.

The results of observations with the triple frequency sounder suggest that it might be possible with its use to find the sizes of fish in a given echo trace and so lead to a physical method of identification.

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